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(54) **Aligning masks and wafers in the manufacture of semiconductor devices**

(57) Method of discriminating stillness of a step exposure apparatus is characterized by the steps of causing a mask and wafer to step relative to each other, repetitively detecting the relative displacement (degree of out-of-alignment) between the mask and wafer, processing to compute a value representing a variation in the displacement measurements, and comparing the computed value with a critical value relating to the attenuation of vibration resulting from the stepping motion to instruct the computation of the amount of further relative movement to be effected between the mask and wafer if the measurement is smaller than the critical value (and assuming the mask and wafer are not yet properly aligned) or to instruct the re-computation of the value if it is larger than the critical value.

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FIG. 1A

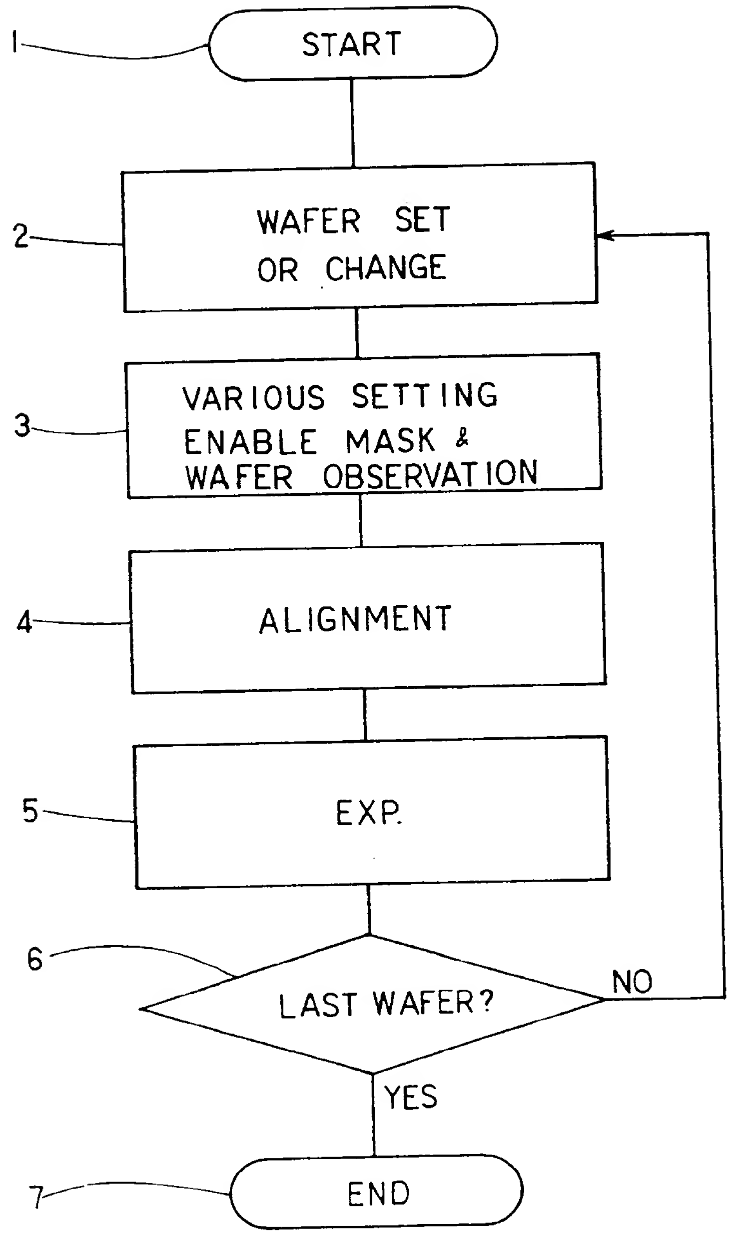
START
WAFER SET
OR CHANGE
VARIOUS SETTING
ENABLE MASK &
WAFER OBSERVATION
ALIGNMENT
EXP.
LAST WAFER?
NO
YES
END
1
2
3
4
5
6
7

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FIG. 1B

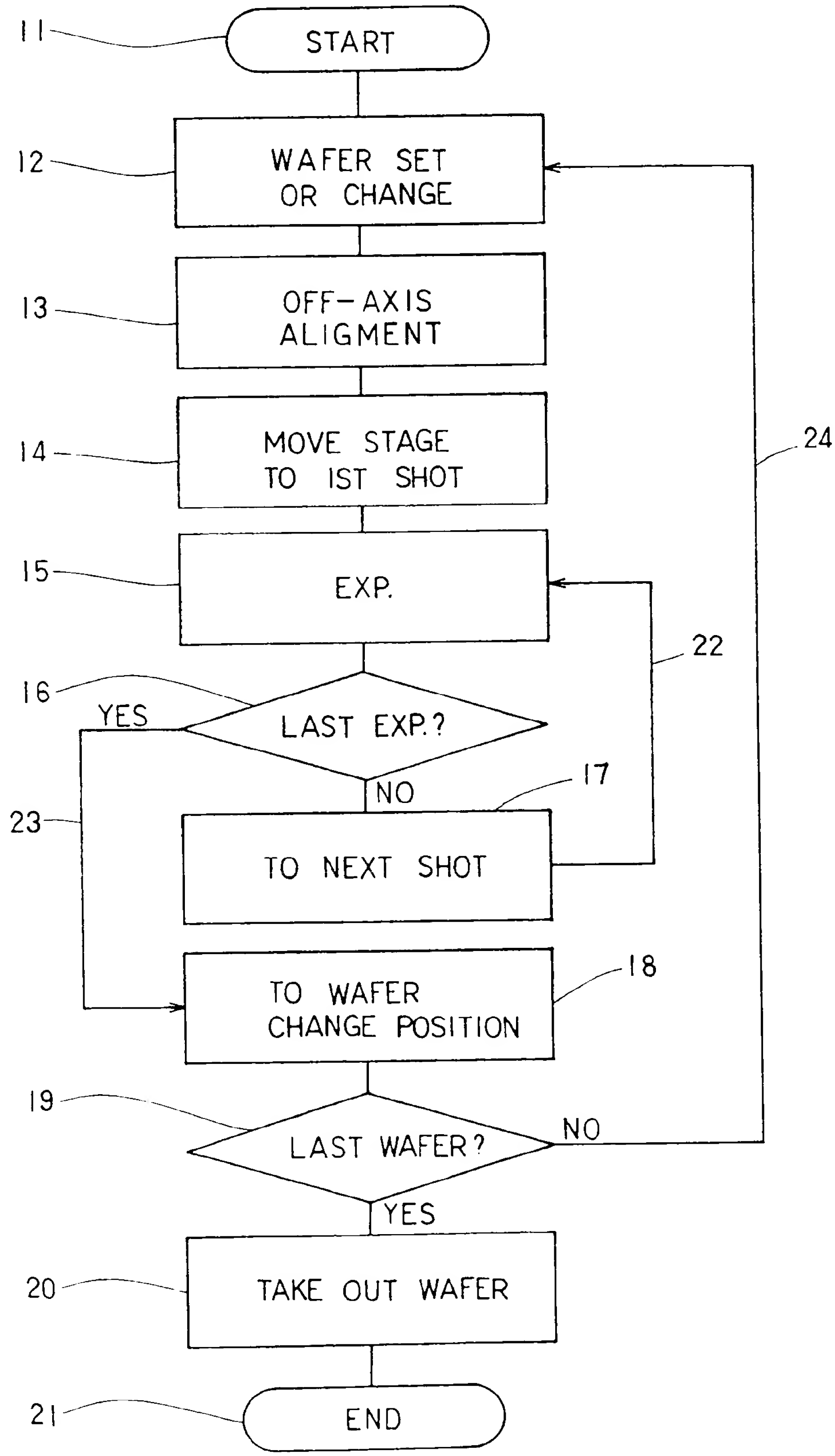
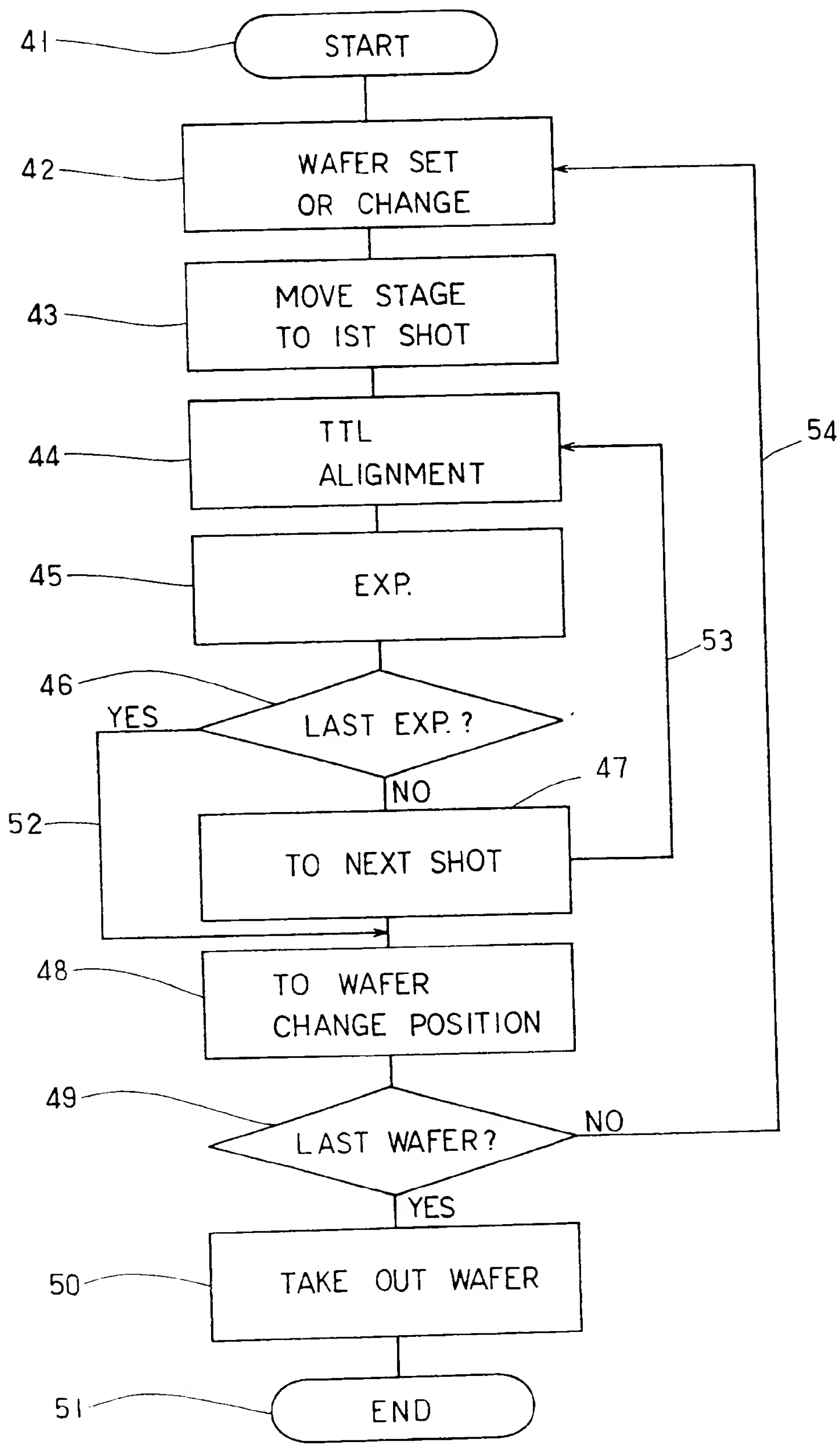


FIG. 1C



41
START
42
WAFER SET OR CHANGE
43
MOVE STAGE TO 1ST SHOT
44
TTL ALIGNMENT
54
45
EXP.
53
46
YES
LAST EXP. ?
NO
47
52
TO NEXT SHOT
48
TO WAFER CHANGE POSITION
49
LAST WAFER?
NO
YES
50
TAKE OUT WAFER
51
END

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FIG. 2

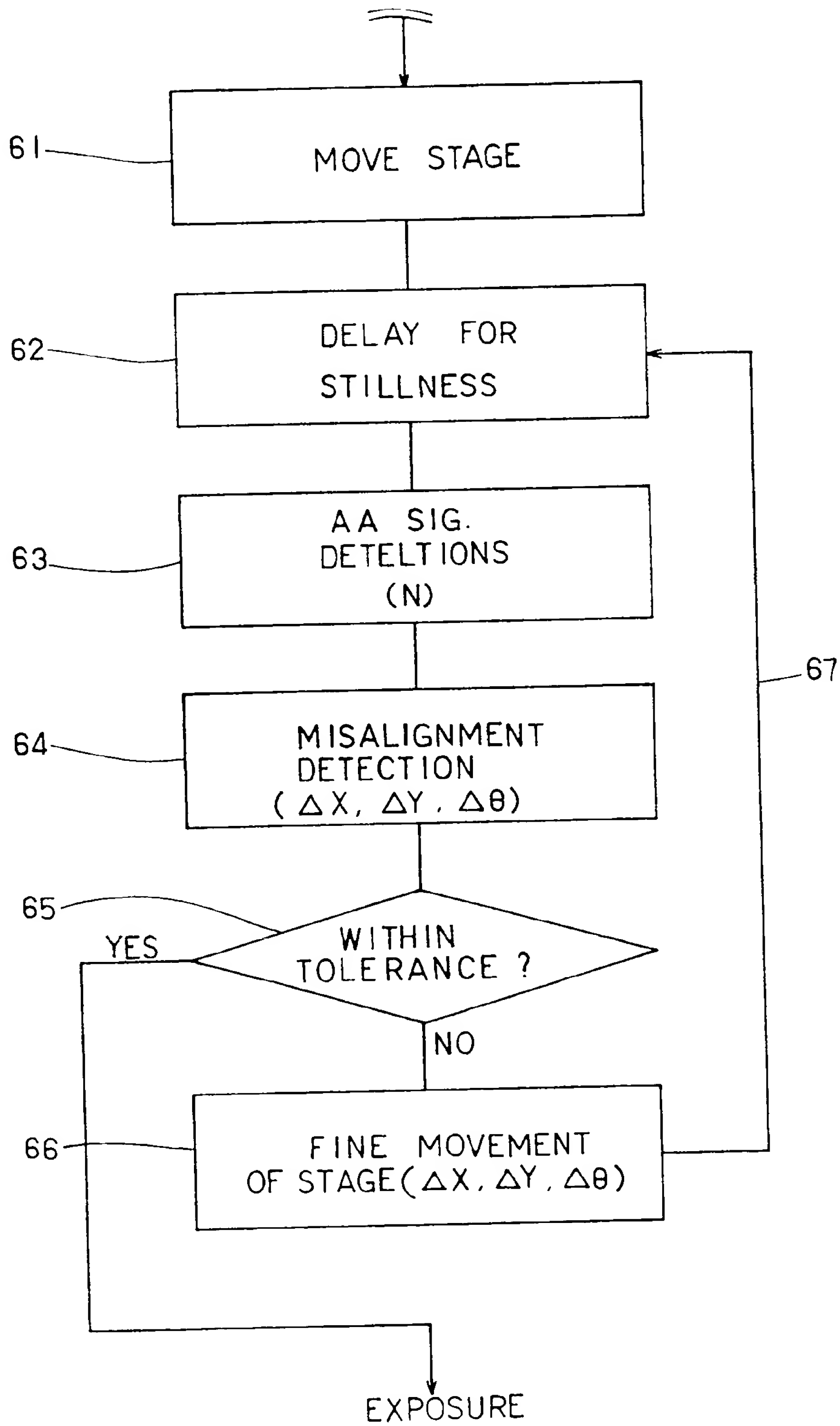


FIG.3

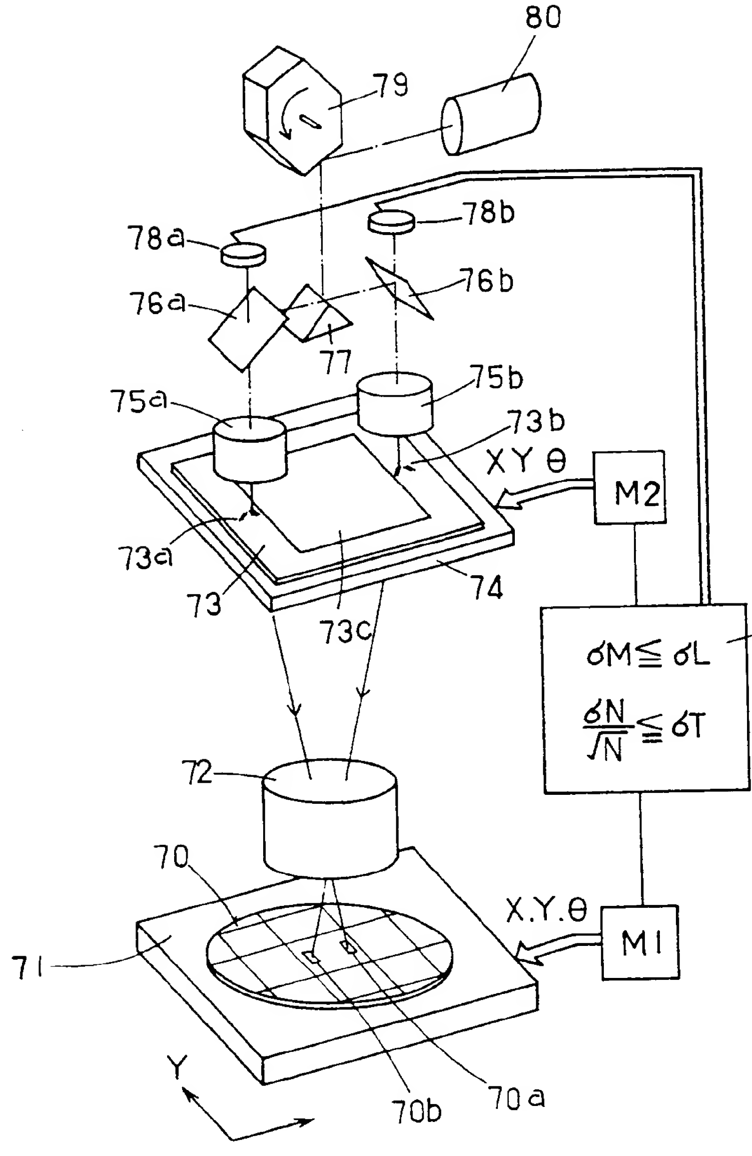
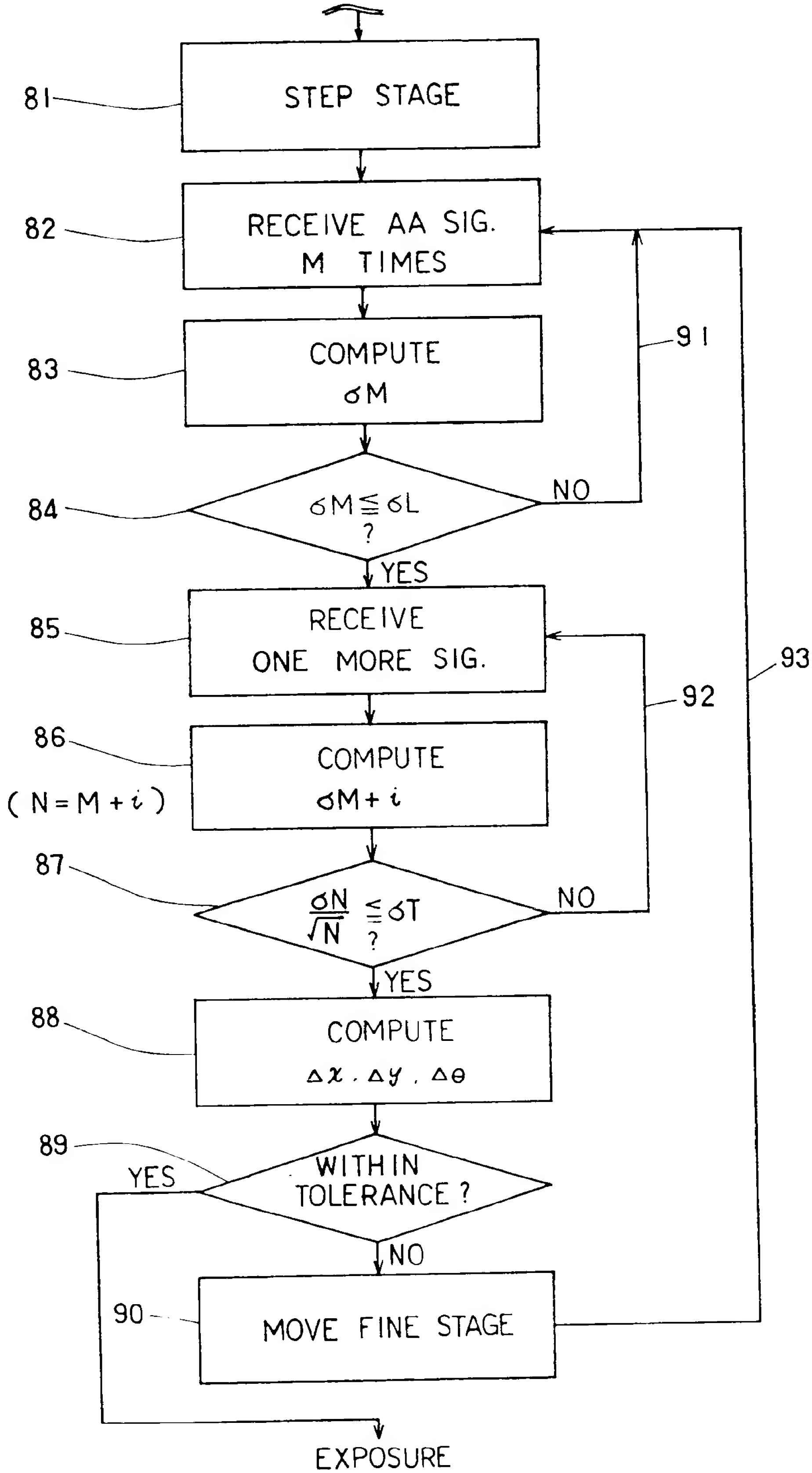

80
79
78a
78b
76a
77
76b
75a
75b
73b
XYθ
M2
73a
73
74
73c
C
σM≦σL
σN/√N≦σT
72
70
X.Y.θ
M1
71
Y
70b
70a

FIG. 4A



STEP STAGE
RECEIVE AA SIG. M TIMES
COMPUTE σM
σM ≦ σL ?
NO
YES
RECEIVE ONE MORE SIG.
COMPUTE σM + i
(N = M + i)
σN/√N ≦ σT ?
NO
YES
COMPUTE Δx, Δy, Δθ
WITHIN TOLERANCE ?
YES
NO
MOVE FINE STAGE
EXPOSURE
81
82
83
84
85
86
87
88
89
90
91
92
93

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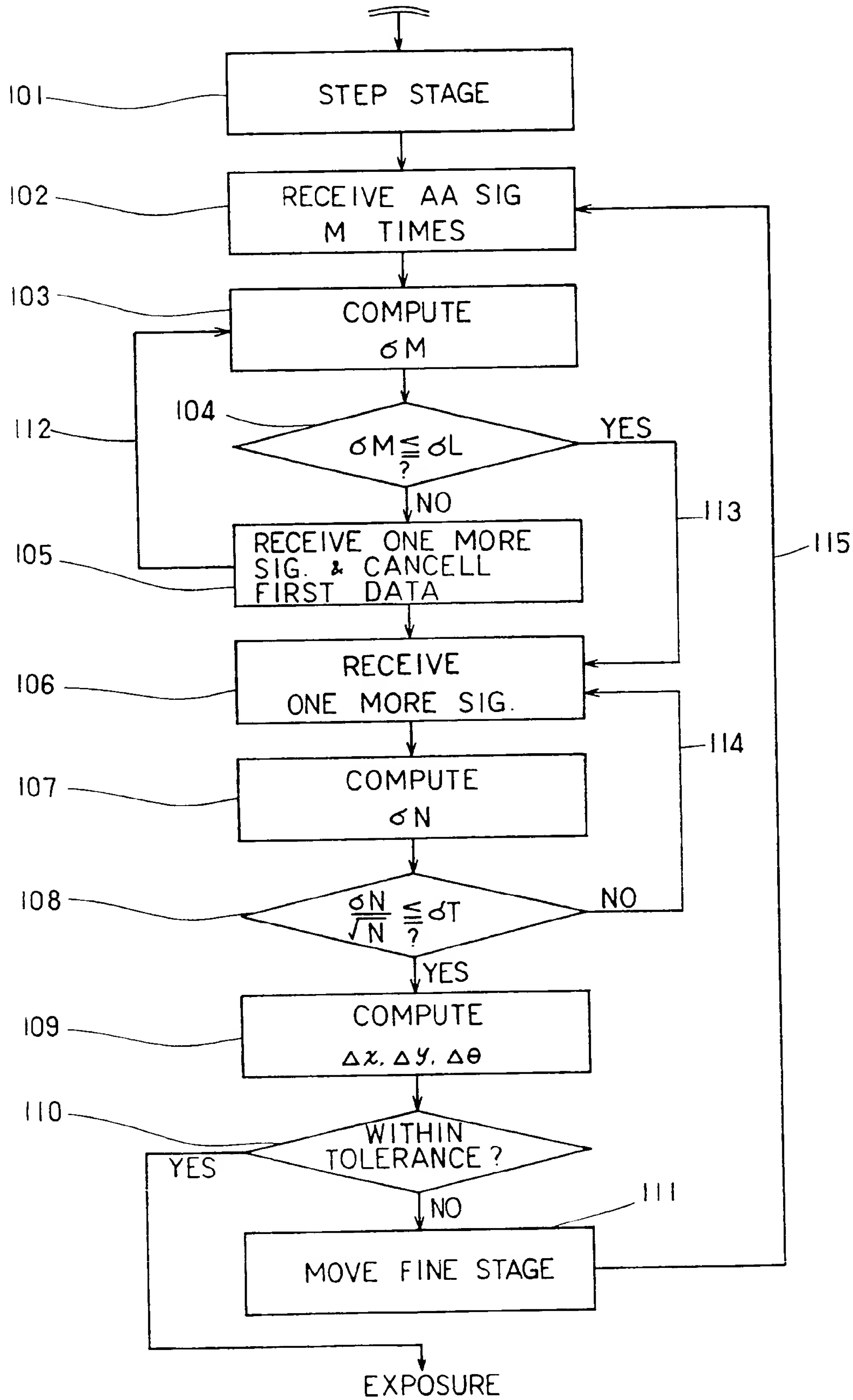
FIG. 4B



SPECIFICATION

Method and device for discriminating stillness of a step exposure apparatus

Background of the invention

Field of the invention

The present invention relates to a method and device for discriminating stillness of a semiconductor exposure apparatus, particularly a step-and-repeat projection alignment and exposure apparatus (stepper) using a reduction optical system.

Description of the prior art

Particularly, the present invention prevents the computation of the degree of alignment from being adversely affected by the relative movement between a photo-mask and wafer which is produced by an oscillation due to the step-and-repeat motion in a stage. The present invention further prevents a variation in detected signals due to various factors such as the reflectivity of the wafer, the surface condition of a photo-register and others from providing an indifinite time required to attain the desired alignment or degrading the accuracy of the alignment.

In general, the semiconductor exposure apparatus (mask aligner) is used for exposing a wafer to the actual element pattern of a mask which functions as an original. Such a semiconductor exposure apparatus utilizes either of a whole surface pattern exposure process characterized by a single shot, or a repetitive (divided) exposure process characterized by a plurality of shots. The whole surface pattern exposure process is used in cases where a wafer is exposed in contact with a mask (contact method), where a wafer is exposed, without using any imaging system, with the wafer being spaced away from a mask by a very small distance (proximity method), where a wafer is maintained spaced away from a mask by a sufficient distance such that they will always be disposed in such a relationship that the pattern on the mask can be imaged on the wafer through an one-to-one imaging system including lenses or mirrors (one-to-one projection method), and so on. The whole surface pattern exposure process exposes the wafer to the actual element pattern on the mask at a time. If it is desired to form a very compactly integrated element, however, the whole surface pattern involves a difficulty in manufacturing a mask, since it has to have, at the unit scale a very fine pattern to which a wafer is to be exposed.

In view of this problem, the repetitive exposure process has been proposed in which a wafer is exposed at its effective area to a pattern on a mask through a plurality of exposure shots by exposing the wafer to the pattern of the mask through a reduction projection lens system having its magnification smaller than one and moving the wafer and mask relative to each other such that the exposed regions on the wafer will not be overlapped one on another throughout the exposure procedure. In this repetitive exposure process utilizing the reduction projection lens system, the pattern on the mask can be enlarged by a factor of the inverse number of the magnification in the imaging system. Therefore, the above difficulty associated with the manufacture of the mask can be decreased.

The repetitive exposure process utilizes either of an OFF-AXIS alignment system or a TTL ON-AXIS alignment system.

In the off-axis alignment system, the alignment pattern on a wafer is first aligned with an alignment optical system fixed outside of a projection optical system. The wafer is then moved accurately to under the projection optical system so that the alignment pattern on the wafer will be aligned indirectly with the alignment pattern on a photo-mask. In the TTL on-axis system, the alignment patterns on a wafer and photo-mask are simultaneously observed through a projection optical system such that the alignment patterns can directly be aligned with each other.

The art of semiconductor elements is being unlimitedly advanced toward a goal at which they are integrated comactly as far as possible and operated at a speed as high as possible. The mask aligner is therefore required to have higher resolving power and high degree of alignment. But, it is one of industrial machines so that higher productivity is also desired.

Figures 1A, 1B and 1C illustrate three basic flowcharts of the prior art alignment and exposure systems (aligners). Figure 1A shows the flowchart of an aligner utilized in the contact method, the proximity method, the one-to-one projection method or the like. In such a system, a wafer is processed by a single alignment and a single exposure. Figure 1B shows the flowchart of a stepper used in the off-axis alignment system in which a wafer is processed through a single alignment and a plurality of exposure steps. A loop including an exposure step is repeatedly carried out through the number of several tens to a hundred and several tens per wafer. To reduce time required in the repetitive exposure loops a stage which can be operated with high accuracy at high speed is provided. Such a stepper has an increased resolving power due to the reduction projection in comparison with the aligner shown in Figure 1A. The stepper also has an increased accuracy of alignment since the wafer can be compensated in expansion and shrinkage by changing the amount of movement in the step stage. However, since the alignment patterns on the mask and wafer have to be independently positioned by different detection systems, and then, the projected pattern of the mask pattern must be moved to be aligned with the wafer pattern while assuring ultimate correctness of the movement. This results in larger number of factors of error. It is difficult to increase the alignment in accuracy, suppressing various errors.

A system which can eliminate the above factors of error while assuring the increased resolving power and alignment accuracy is a stepper utilized in the TTL on-axis alignment system (die-by-die alignment system) in which the alignment patterns on the mask and wafer can manually be aligned with each other through a lens system. Figure 1C shows the flow-

chart of such a system in which a loop 53 includes steps of alignment, exposure and stage movement. As a result, the system requires an additional time which is equal to the operational time of alignment multiplied by the number of steps in comparison with the stepper in the off-axis alignment system. For the TTL on-axis system stepper, therefore, it is an essential proposition that time is reduced particularly in the alignment operation to assure the necessary throughput in a production machine.

For example, when fifty exposures per wafer is required and if a throughput of 50 wafers/hour is expected, the total time afford to alignment operation plus exposure plus stage movement should be equal to about one or two seconds. Reduction of time by 0.1 seconds corresponds to the saving of five seconds per wafer. The throughput can be increased by three of four wafers per hour.

It is of course that the reduction of time in alignment is a common theme for all the prior art aligners although the degree of importance is different from one another. Figure 2 shows the slightly detailed portion of the flowchart shown in Figure 1B in connection with the alignment operation. If this flowchart portion is considered in respect to time required in the alignment operation, there are two significant problems one of which is a delay time t in Step 62. A rest time after the stage has been moved (time through which an oscillation produced in the system can be deemed to be stopped) is variable depending on the amount of movement in the stage or the selection of a stage to be moved, for example. To obviate this, a constant delay time t is provided by adding some safety time to the longest time of the times produced in the above situations. This method, however, deny the possibility of speeding-up.

The other problem is the number of loops 67 through which detections and movements are repeatedly carried out. Necessarily, as the number of loops 67 is increased, loss of time is increased.

A certain fixed relation is among four factors, an accuracy σA in AA (automatic alignment) detection, an accuracy σS in the movement of the stage, a acceptable-or-not discrimination (tolerance T) meaning an expected accuracy and the number of movement R (the number of re-adjustments of the stage until an alignment is attained). If three factors of them are determined, the remaining factor can substantially be determined. A single AA signal is insufficient to assure the necessary alignment accuracy in the system so that plural of the same is taken and the accuracy is improved by averaging all the received signal detection values. If detected signal values of N in number are averaged, the accuracy is improved substantially by a factor of $\sqrt{N}$. If σS is deemed to be an inherent value in the system and when the tolerance T and the number of movements R are set as expected values, the number N of received signals can necessarily be determined. In the prior art, the number N of received signals was set as an inherent value in the system.

Actually, the variation in received signals is variable depending on different steps in the semiconductor production process or different lots of production in the same process. Accordingly, the variation in an averaged value of received signals of N in number also is variable. As a result, the number of movements is always varied contrary to expectation so that the throughput will be influenced. On the other hand, the accuracy of alignment can be determined based on the signal detection accuracy σA, the accuracy of movement σS and the tolerance T. If the detection accuracy σA is varied, the final accuracy of alignment also is varied.

As will be understood from the foregoing, the alignment operation in the prior art is disadvantageous in that it is impossible to reduce time required in the alignment and yet that the expected throughout and alignment accuracy are unstably and always varied.

Summary of the invention

It is an object of the present invention to eliminate the disadvantages of the prior art, to reduce time required in alignment operation and to assure the accuracy of, and the time required for, the alignment which are stable relative to the expected values.

Another object of the present invention is to provide means for assuring the accuracy of, and the time required for, the alignment which are always stable independently of a difference between steps in the integrated circuit production process of a variation in alignment detection accuracy due to a difference between lots.

Still another object of the present invention is to provide means for improving the throughput by initiating the reception of AA signals with the necessary minimum stand-by time for the stillness after the stage stop.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiment of the present invention taken in conjunction with the accompanying drawings.

Brief description of the drawings

Figure 1A is a basic flowchart of an aligner used in the contact method, proximity method and one-to-one projection method;

Figure 1B is a basic flowchart of an off-axis tipe stepper;

Figure 1C is a basic flowchart of a TTL die-by-die tipe stepper;

Figure 2 is a flowchart of the prior art alignment operating section;

Figure 3 is a perspective view of one embodiment according to the present invention; and

Figures 4A and *4B* is flowcharts of the alignment operating section according to the present invention.

Description of the preferred embodiments

Figure 3 shows the basic construction in the TTL on-axis system together with a wafer 70 having alignment patterns 70a and 70b formed thereon. Although a set of alignment patterns are actually provided for each shot area, only one set of alignment patterns is illustrated in Figure 3 for the simplicity of explanation. The system includes a

wafer stage 71 which holds the wafer 70 thereon and is moved in the directions X and Y by means of a drive mechanism M1. The system also includes a mask stage 74 which holds a photo-mask (reticle) 73 thereon and is moved in the directions X, Y and θ by means of a drive mechanism M2 in two modes of coarse and fine movements. The photo-mask 73 includes alignment patterns 73a, 73b and an actual element pattern 73c which are formed thereon. The mask stage 74 includes an unshown opening formed therethrough such that the projection of the alignment and actual element patterns will not be disturbed. The system further includes a reduction projection optical system 72. The step motion of the wafer is carried out by moving the wafer stage 71 while the alignment between the photo-mask and wafer is attained by moving the mask stage 74 or wafer stage 71.

The system further includes objective lenses 75a, 75b; semi-transmission mirrors 76a, 76b; an optical path splitting prism 77; photo-cells 78a, 78b; a polygonal mirror 79 and a source of laser beam all of which define a signal detection system. Laser beam from the source 80 is scanningly deflected by rotating the polygonal mirror 79 at a constant speed. The laser beam is then incident on the prism 77 and exits leftwardly therefrom in the former half of a single scanning motion and rightwardly therefrom in the latter half of the same scanning motion. Each of the laser beam portions from the prism 77 is reflected by the corresponding semi-transmission mirror 76a or 76b to the respective objective lens 75a or 75b. After passing through the corresponding objective lens 75a or 75b, the laser beam portion scans the photo-mask 73. The laser beam portion then passes through the projection lens 72 to scan the wafer 70. After reflected by the alignment patterns 70a and 70b on the wafer 70, the laser beam portions are incident back on the projection lens 72 and then incident on the photo-cells 78a and 78b through the objective lenses 75a, 75b and semi-transmission mirrors 76a, 76b together with the laser beam portions reflected by the alignment patterns on the mask. When the photo-cells detect the laser beam portions, they generate detection signals which are in turn inputted to a control unit C. The detection signals are processed in accordance with flow-charts decribed hereinafter with the results being used to move the stage 74 through the drive mechanism M2 to attain an alignment between the wafer 70 and the photo-mask 73.

Above the photo-mask 73 there is provided an illumination system (not shown) which is adapted to illuminate the actual element pattern C on the photo-mask when the alignment is completed and after the detection system is retracted out of the optical path in the illumination system.

Figures 4A and 4B show flow-charts of the alignment operating section in the embodiment of the present invention. Each of these flowcharts corresponds to the respective alignment steps 4, 13 and 44 shown in Figures 1A, 1B and 1C.

In the TTL on-axis type stepper, the stage on which the wafer is placed is moved to and stopped at a position near the exposure position (Step 81). At the same time, the detection system is actuated to initiate the reception of AA signals (for example, intervals between a plurality of bars of the alignment marks) until a predetermined number M of signals are received (Step 82). Subsequently, a computation section computes a deviation (variance) σM in the received detection signals of M in number (step 83). Actually, the reception of signals and the computation are simultaneously carried out to successively compute a deviation σl in the detected signals of i in number which have been received till that time.

In the first reception of signals of M in number, there is necessarily a relative oscillation (vibration) between the mask and wafer since the reception is initiated immediately after the stage has been stopped. The deviation σM is therefore larger than that after the oscillation has been stopped. If a critical value σL suitable for the system has been set and is compared with the deviation σM (Step 84) and when the critical value is smaller than the deviation σM, the previous data is cleared and the next receiving operation for signals of M in number is initiated (Step 91).

The critical value can be determined based on experiments in which the process of attenuation in any oscillation produced in the whole system upon movement of the particular stage is examined and in which the influence to accuracy in detection due to any degree of oscillation is determined.

In an other embodiment of the present invention shown in Figure 4B, if the acceptable-or-not discrimination is "not", the next reception of signals is effected and at the same time the first data (oldest data) is discarded (Step 105). Consequently, the computation of deviation σM will be carried out based on the latest data of signals of M in number (Step 103).

If the deviation σM is compared with the critical value σL, the date of oscillation after the movement of the stage can subsequently instantaneously be discriminated. If the deviation σM becomes equal to or smaller than the critical value σL, the procedure goes out of this routine 91 or 112. Thereafter, the procedure may use the data of M in number which have been used in the discrimination of $\sigma M \leqq \sigma L$ or may sample new data and use the same. The embodiment shown in Figure 4 is in the case of the former.

In the next step, the next signal is received to compute $\sigma M+i$ ($i = 1, 2, 3 \ldots$) in such a manner that it is accumulated on the previous data (Steps 86 and 107). The total number of samples, $N=M+i$, used to compute the value $\sigma M+i$ is utilized to compute a function of deviation $\sigma N/\sqrt{N}$ which is in turn compared with a preset critical value σT (Steps 87 and 108). In Step 87 or 108, the next signal is succeedingly received along a loop 92 or 114 until the value $\sigma N/\sqrt{N}$ is equal to or smaller than σT.

The function of deviaton $\sigma N/\sqrt{N}$ is exemplified for such a purpose that if a variation (variance) in detected alignment signals is varied to increase for any reason, the number of receiving operations is increased. If the variance is relatively small, the number of receiving operation is decreased. Thus, the variance in the average of the received data can

be make constant.

Therefore, the formula $\sigma N/\sqrt{N}$ is not necessarily used and the value σN is not limited to the deviation if it can represent any variation in detected signals.

After the procedure has passed through Step 87 or 108 at the discrimination of $\sigma N/\sqrt{N} \leqq \sigma T$, the average value of data will always have a constant variance.

Although the flowcharts have been described as if the detection signals are from a single position, it is desirable to use two data from different positions (XL, YL) and (XR, YR). Based on averages of the respective data $(\overline{XL}, \overline{YL})$ and $(\overline{XR}, \overline{YR})$, the amounts of movement relative to target values, $\Delta X = (\overline{XL}+\overline{XR})/2$, $\Delta Y = (\overline{YL}+\overline{YR})/2$, $\Delta\theta = (\overline{YL}-\overline{YR})/2$ are computed (Steps 88 and 109).

It is discriminated whether or not these computed values are acceptable, based on preset tolerance values (Steps 89 and 110). If they are not acceptable, the movements are executed by the given amounts ΔX, ΔY and $\Delta\theta$ (Steps 90 and 111). Thereafter, the program again enters the loop in which signals are received (Steps 93 and 115). If acceptable, the preparation for an exposure step starts.

According to the improved alignment flowcharts as shown in Figures 4A and 4B, a reliable timing for starting reception of signals can be judged at real-time by monitoring an oscillation resulting from the movement of the stage to eliminate the loss of time due to the indiscriminate delay time so that the throughput can be improved. This advantage can be accomplished only by the inherent function in the system without any additional hardware (for example, new mechanism) in accordance with the present invention.

The present invention provides another advantage in that stable alignment accuracy and throughput can always be obtained in no connected with any difference between steps of wafer, any difference between lots or others.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.

CLAIMS

1. A method comprising the steps of:
providing the relative movement between a mask and wafer;
repetitively detecting a displacement between said mask and wafer;
processing to compute a measurement representing a variation in the detected displacements; and
comparing said measurement with a first critical value relating to the degree of stillness in a system, and proceeding to a step for computing the amount of movement for moving said mask and wafer to align one with the other if said measurement is smaller than said critical value, and proceeding to instructing a re-computation for said measurement if said measurement is larger than said critical value.

2. A method as defined in claim 1 wherein said re-computation for said measurement is executed by using a plurality of newly detected displacements between said mask and wafer.

3. A method as defined in claim 1 wherein said re-computation for said measurement is executed using at least one newly detected displacement between said mask and wafer added to the previously detected displacements and removing the previously detected displacements equal in number to the newly added displacements.

4. A method as defined in claim 1 wherein said step for computing the amount of movement for the alignment movement comprises the steps of detecting at least one new displacement between said mask and wafer; adding said newly detected displacement to the previously detected displacements with these all displacements being used to compute a predetermined function of deviation; and comparing the computed function of deviation with a second critical value.

5. An apparatus comprising:
as mask stage for moving a mask;
a wafer stage for moving a wafer;
step drive means for stepping one of said mask and wafer stages;
alignment drive means for moving one of said mask and wafer stages to align said mask and wafer with each other,
means for detecting a displacement between said mask and wafer;
means for computing an operational value for operating said alignment drive means on the basis of said displacement; and
means for determining the degree of stillness of the apparatus to determine the detected displacement to be imputted to said computing means.

6. An apparatus as defined in claim 5, further including a projection optical system for projecting the image of said mask onto said wafer in a reduced scale and wherein said detecting means is adapted to sense said wafer through said projection optical system.

7. An apparatus as defined in claim 5 wherein said discriminating means includes means for computing a variance based on a plurality of displacements; means for comparing the variance with a first critical value relating to such attenuation of oscillation in the apparatus that error will not substantially occurs in the computed results; and means for determining a positional error used to compute the operational value if the variance is smaller than said first critical value.

8. An apparatus as defined in claim 5 wherein said discriminating means includes means for computing a function of deviation based on a plurality of displacements; means for comparing the function of deviation with a second critical value relating to an acceptable variation in signals detected by said detection means; and means for determining a displacement to be used for computing an operational value if the function of deviation is smaller than said second critical value.

9. An apparatus for achieving a desired substantially stationary positional relationship between first and second objects, comprising

means for producing relative movement of said objects such that the objects assume said positional relationship,

means for detecting the relative position of the objects when moved to assume said positional relationship,

means responsive to said detecting means for determining when said objects achieve a desired degree of stillness, and

means for processing at least one of said objects when said determined desired degree of stillness is achieved.

10. An apparatus according to claim 9 adapted to produce relative movement of a semiconductor wafer and a mask, wherein said processing means includes means for exposing the wafer to radiation through the mask.

11. An apparatus according to claim 10 adapted to produce a single exposure through the mask for the wafer.

12. An apparatus according to claim 10 having an off-axis alignment system.

13. An apparatus according to claim 10 having a TTL alignment system.

14. Apparatus for achieving a plurality of different positional relationships of a mask and wafer, substantially as hereinbefore described with reference to Figure 3 and 4A or B of the accompanying drawings.

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